Chapter Two

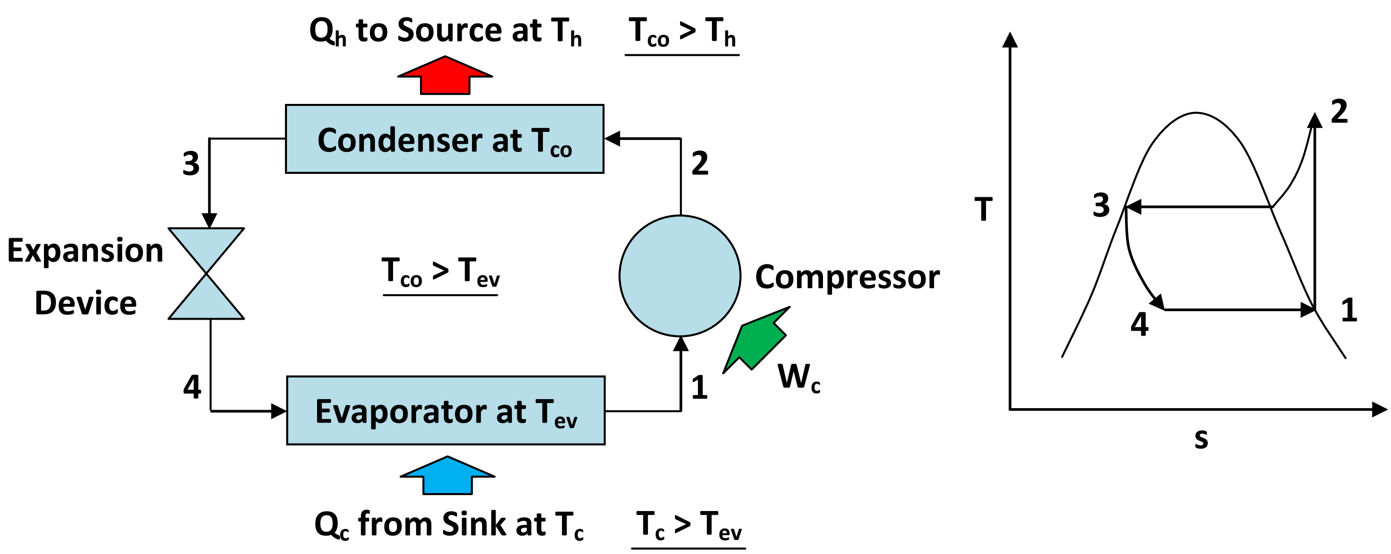
Refrigeration

2.1 Introduction:

Refrigeration means lowering the temperature of a certain space, container or material by transporting its thermal content (heat) to another "place" or reservoir of higher temperature. The refrigerated place having the low temperature is usually referred to as (Sink) and that of higher temperature is called (Source). So the refrigeration reverses the usual trend of nature of transferring heat from high to low temperature levels. Transporting heat from low to high temperature reservoirs requires incorporation of external mechanical work. Refrigeration incorporating mechanical work is called (Mechanical Refrigeration) to distinguish it from the other type, namely, (Absorption Refrigeration) which incorporates external source of heat instead of external work.

2.2 Mechanical Refrigeration:

In this type of refrigeration a certain working fluid (Refrigerant) is used as a medium for the transport of heat from the low to high temperature reservoirs. The refrigerant is circulated in a closed cycle called (Refrigeration Cycle). The basic components of any refrigeration cycle are: **Evaporator, Compressor, Condenser and Expansion Device.** The cycle is also called **Vapor Compression Cycle.**



(a): Schematic diagram

(b): Temperature−entropy T−s diagram of an ideal cycle

Fig. (2.1): Simple refrigeration cycle.

2.3 Processes of a simple ideal refrigeration cycle

To study the thermal performance of refrigeration cycles, a hypothetical operation is assumed where the following four reversible processes occur consecutively in the cycle components:-

- Reversible-adiabatic (isentropic) compression in compressor (1 – 2).
- Reversible rejection of heat at constant pressure in condenser (2 – 3).
- Constant enthalpy expansion (throttling) in expansion device (3 – 4).
- Reversible addition of heat at constant temperature (isothermal) in evaporator (4 – 1).

2.4 Important definitions

Refrigeration effect (q_{ev}):

It is defined as the enthalpy change across the evaporator per unit mass flow rate: −

$$q_{ev} = h_1 - h_4 \qquad 2.1$$

Refrigeration capacity (Q_{ev}):

It is the total rate of heat transfer in the evaporator:

$$Q_{ev} = \dot{m}(h_1 - h_4) = \dot{m}q_{ev} \qquad 2.2$$

Compressor work (W_c):

It is the total energy required by the compressor to circulate the refrigerant mass flow rate:

$$W_c = \dot{m}(h_2 - h_1) \qquad 2.3$$

Rejected Heat (Q_{co}):

It the amount of heat rejected by the condenser to the environment or to an adjacent cooling heat exchanger: −

$$Q_{ev} = \dot{m}(h_2 - h_3) \qquad 2.4$$

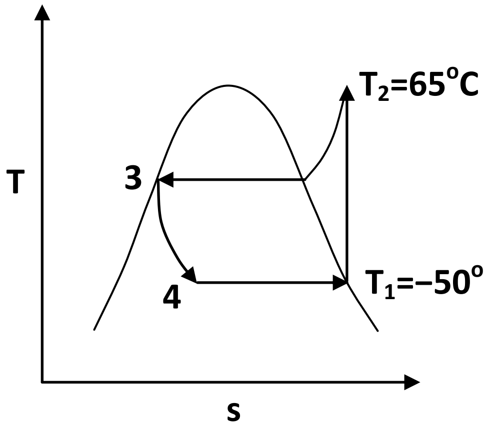
Coefficient of Performance (COP):

It is a measure of the efficiency of the refrigeration cycle. COP is defined as amount of heat transferred to the evaporator (Q_{ev}) per unit work supplied to the compressor. The value of COP is usually greater than one for efficient refrigeration cycles. COP is calculated as follows: −

$$COP = \frac{Q_{ev}}{W_c} = \frac{\dot{m}(h_1 - h_4)}{\dot{m}(h_2 - h_1)} = \frac{h_1 - h_4}{h_2 - h_1} \qquad 2.5$$

Ex. 2.1 A simple ideal refrigeration cycle working on R134a operates with −50°C inside the evaporator. If the maximum temperature in the loop is 65°C and the refrigerant mass flow rate is 0.01 kg/s then find: −
a) Compressor work. b) Refrigeration capacity. c) COP.

Sol.
At T_1=−50°C from sat. tab of R134a $h_1=h_g$=368 kJ/kg $s_1=s_g$=1.7819 kJ/(kg K) $s_2=s_1$
At T_2=65°C and s_2=1.7819 kJ/(kg K) from super. tab.
P_2=1100 kPa h_2=445 kJ/kg
At P_2=1100 kPa from sat. tab. $h_3=h_f$=256 kJ/kg $h_4=h_3$
W_c=0.01(445−368) **W_c=0.77 kW**
Q_{ev}=0.01(368−256) **Q_{ev}=1.12 kW**
COP=1.12/0.77 **COP=1.45**



Ex. 2.2 A simple ideal vapor compression refrigeration cycle works with a COP of 3 and an evaporation pressure of 80 kPa. If R410a is circulated inside the loop with a mass flow rate of 20 g/s and the compressor consumes 1800 W then evaluate: −
a) Refrigeration capacity. b) Condenser pressure. c) Loop maximum temperature.

Sol.
At P_1=80 kPa from sat. tab of R410a $h_1=h_g$=399.2 kJ/kg
T_1=−56°C $s_1=s_g$=1.9571 kJ/(kg K) $s_2=s_1$
$W_c = \dot{m}(h_2 - h_1)$ 1.8=0.02(h_2−399.2) h_2=489.2 kJ/kg
$COP = \frac{Q_{ev}}{W_c}$ $3 = \frac{Q_{ev}}{1.8}$ **Q_{ev}=5.4 kW**
At h_2=489.2 kJ/kg and s_2=1.9571 from super. tab. of R410a
P_2=1700 kPa
T_2=78°C T_3=26.19°C